VERIFICATION OF TRANSLATION

I, ITOME Shigeki, a citizen of Japan, currently residing at 201 4-19-3 Senrioka-higashi, Settsu-city, Osaka, Japan, hereby declare:

That I am fully familiar with the English language and with the Japanese language in which the accompanying Japanese patent application No. 096075/2000 was prepared;

That the annexed English text is believed by me to be a true and accurate translation of the text of said Japanese patent application; and

That all statements made herein of my knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed at Osaka, Japan
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[TITLE OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] REFLECTIVE LIQUID CRYSTAL DISPLAY DEVICE

[CLAIMS]

[CLAIM 1]

A reflective display device having a pair of substrates, a middle layer provided between the pair of substrates, and a retro-reflector, characterized in that a pitch of smallest unit structures of the retro-reflector is larger than 0 mm and not more than 5 mm.

[CLAIM 2]

The reflective liquid crystal display device as set forth in claim 1, wherein a plane of a unit structure of the retro-reflector is a light absorbing surface.

[CLAIM 3]

The reflective display device as set forth in claim 1 or 2, wherein at least one lens sheet is provided on a front surface of the retro-reflector.

[CLAIM 4]

The reflective display device as set forth in any one of claims 1 through 3, wherein the retro-reflector is any one of a corner cube array, a micro sphere array, and a micro lens array.

[CLAIM 5]

The reflective liquid crystal display device as set forth in claim 4, wherein the reflective liquid crystal display device adopting the corner cube array is so arranged that light absorbing sites are provided on vertices and sides of the corner cube, or that light reflected at vertices and sides of the corner cube is shielded.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[INDUSTRIAL FIELD OF THE INVENTION]

The present invention relates to a reflective liquid crystal display device, and particularly to a reflective liquid crystal display device which is capable of clear full-color display with a bright white state and a high contrast ratio without a polarizer.

[0002]

[PRIOR ART]

Liquid crystal display devices have been widely used as thin and light-weight color display devices. Among such color liquid crystal display devices, most commonly used are transmissive liquid crystal display devices which employ a back light source. The transmissive liquid crystal display devices have been used in an increasingly wider variety of field for various uses.

[0003]

What contrasts to the transmissive liquid crystal display devices are reflective liquid crystal display devices which employ other display modes. The reflective liquid crystal display devices do not require a back light, thus reducing power for the light source and saving a space or weight thereof. That is, power consumption of the display device can be reduced as a whole, which permits the use of smaller batteries, making the reflective liquid crystal display devices suitable for equipment which is required to be thin and light-weight. Further, given the same size or weight of the equipment, the reflective liquid crystal display devices allow the use of larger batteries, making it possible to greatly increase the operation time.

[0004]

Further, the reflective liquid crystal display devices also have advantages over other display devices in view of contrast ratio characteristics of the display. That is, in self-emitting display devices such as a CRT, a significant reduction in contrast ratio is incurred under day light outside. Such a significant reduction in contrast ratio occurs also in transmissive liquid crystal display devices, that low reflection films are coated on, when the intensity of the surrounding light is much larger than display light,

as in the case under direct sun light. On the other hand, the reflective liquid crystal display devices can obtain display light which is proportional to the quantity of the surrounding light, and can avoid a reduction in contrast ratio, and therefore are suitable particularly for portable information terminals, digital video cameras, or portable video cameras, etc., which are often used outside.

[0005]

Despite such promising applications, there has been no reflective color liquid crystal display device which meets the demand for practical applications. This is chiefly due to the fact that conventional reflective color liquid crystal display devices were insufficient in terms of reflectance contrast ratio, full-color display, high-definition display, and their ability to display moving images.

[0006]

The following describes conventional reflective liquid crystal display devices in more detail. Currently, the reflective liquid crystal display devices which are widely used employ a pair of or a single polarizer. The operation modes of these liquid crystal display devices include a twist nematic mode ("TN mode" hereinafter) which performs display by controlling optical rotatory power of

the liquid crystal layer by an electric field, a birefringence mode ("ECB mode" hereinafter) which performs display by controlling birefringence of the liquid crystal layer by an electric field, and a mix mode, which is a combination of the TN mode and the ECB mode.

[0007]

Meanwhile, there have been known reflective liquid crystal display devices which do not employ a polarizer. Guest-Host-type liquid crystal elements, which incorporate a dye in liquid crystal, have been developed for this mode, which, however, had the problem of low reliability due to the addition of the dichroic dye, and the problem of low contrast ratio which is posed by the low dichroic ratio of the dye. This deficiency in contrast ratio in particular results in a significant reduction in color purity in color display using a color filter. Therefore, such reflective liquid crystal display devices which lack a contrast ratio need to be combined with a color filter having high color purity. The reflective liquid crystal display devices therefore have the problem of low brightness when the high color purity color filter is used, which spoils the advantage of high brightness of the mode which omits the polarizer.

[0008]

In order to overcome the foregoing problems, there has been developed a liquid crystal display element of a mode which employs a polymer-dispersed-type liquid crystal or a cholesteric liquid crystal, which is intended for bright and high-contrast ratio display without using a polarizer or a dye. These modes take advantage of the characteristic of the liquid crystal layer which is optically switched between a transmissive state and a scattering state, or between a transmissive state and a reflective state, by controlling an applied voltage to the liquid crystal layer. Further, no polarizer is required in these modes and the efficiency of using light can be improved. Further, from the perspective of evaluation on color fidelity, a desirable white state can be expected in these modes compared with the TN mode or ECB mode, because the wavelength dependency is low and the problem of absorption profile of the polarizer itself, i.e., the problem of the polarizer absorbing blue light and the light transmitting through the polarizer is rendered yellow, is not posed.

[0009]

Such a mode is disclosed, for example, in Japanese Unexamined Patent Publication No. 186816/1991 (Tokukaihei 3-186816). In the liquid crystal display device

in this publication, a polymer-dispersed-type liquid crystal is disposed on a black substrate, wherein a white/black state is performed by the white state, which is rendered by the scattering state of the polymer-dispersed-type liquid crystal which appears murky under no applied voltage, and by the black state, which is rendered by the transmissive state of the polymer-dispersed-type liquid crystal through which the underlying black substrate becomes visible under applied voltage.

[0010]

USP 3,905,682, (published on September 16, 1975) discloses a liquid crystal device having a light modulator employing light scattering liquid crystal and a retro-reflector. Tokukaishou 54-105998 (published on August 20, 1979) discloses a reflective liquid crystal display device having a light modulator employing light scattering liquid crystal or guest host mode liquid crystal, a louver, and a retro-reflector.

[0011]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

However, in the liquid crystal display device of the foregoing publication No. 3-186816, only the backward scattered light from the polymer-dispersed-type liquid

crystal contributes to reflectance of the white state in the white state, and the forward scattered light is absorbed entirely by the black substrate, and the actual efficiency of utilizing light suffers greatly.

[0012]

In the liquid crystal display device disclosed in USP 3,905,682, a black state is realized when the liquid crystal layer is in a transmissive state. A display quality of the black state by retro-reflection is dependent only on retro-reflectivity, and is strongly influenced by the size of the smallest unit structure of the retro-reflector. However, this patent USP 3,905,682 does not teach a mechanism for realizing a black state or a size of the smallest unit structure of the retro-reflector. Further, the retro-reflector disclosed in the embodiment of this patent is a retro-reflector which is realized by a corner cube array or an array of tiny spheres, neither of which, however, possess sufficient retro-reflectivity, and a desirable black state cannot be obtained. Further, this patent is silent as to a detailed structure of a retro-reflector with sufficient retro-reflectivity.

[0013]

In the reflective liquid crystal display device disclosed in the foregoing publication No. 54-105998,

louvers having an absorbing site are disposed on the front side of the retro-reflector on the side of the viewer, and since the retro-reflector is covered with the louvers with respect to light rays incident on the liquid crystal display device from the side of the viewer, all the incident light is absorbed at the absorbing site of the louvers to realize a desirable black state, and the light rays which are incident on the liquid crystal display device from the side of the light source directly reach the retro-reflector through the louvers. However, this publication is also silent as to the size of the smallest unit structure of the retro-reflector, and a regulation for realizing a black state, and, while it solves the problem of the USP 3,905,682, brightness in white state suffers because the area occupied with the absorbing site of the louvers is too large.

[0014]

The present invention was made in view of the foregoing problems and it is an object of the present invention to provide a reflective liquid crystal display device with a bright white state and a high contrast ratio.

[0015]

[MEANS TO SOLVE THE PROBLEMS]

In order to achieve the foregoing object, the

inventors of the present invention had made devoted investigations and found an arrangement including light scattering liquid crystal on a reflector, realizing both a desirable black state utilizing a transmissive state of the light scattering liquid crystal and a desirable white state utilizing a light scattering state of the light scattering liquid crystal. This arrangement is not only effective for a liquid crystal display device adopting the light scattering liquid crystal, but also effective for any display devices which switches between the transmissive state and the light scattering state.

[0016]

The light scattering liquid crystal may be a polymer-dispersed-type liquid crystal, a nematic-cholesteric phase transition liquid crystal, a liquid crystal gel, or the like. In a mode employing a cholesteric liquid crystal which switches between a transmissive state and a reflecting state, or a mode employing the polymer-dispersed-type liquid crystal having holographic function, the present invention is applicable when the liquid crystal layer in the reflecting state is rendered scattering by some means. That is, the present invention is applicable as long as the liquid crystal layer is so arranged as to switch between the

transmissive state and a state in which at least scattering effect is rendered. In the former case, the liquid crystal layer is rendered scattering by controlling a domain size of liquid crystal molecules. As for the latter case, scattering is rendered by exposure of scattering light. With the reflecting function, it is possible to add off-axis property to the reflective liquid crystal display device. Thus, it is possible to efficiently utilize incident rays having various incident angles.

[0017]

Namely, a reflective liquid crystal display device of the present invention includes a pair of substrates, a middle layer provided between the pair of substrates, and a retro-reflector, wherein a pitch of smallest unit structures of the retro-reflector is larger than 0 mm and not more than 5 mm. With this arrangement, it is possible to prevent adverse effects on black state, which are caused by the smallest unit structures of the retro-reflector, thus realizing both desirable brightness of white state and a desirable contrast ratio.

[0018]

Further, in the foregoing reflective liquid crystal display device, a plane of the unit structures of the retro-reflector realizes a light absorbing surface. With this

arrangement, it is possible to prevent adverse effects on black state, which are caused by insufficient retro-reflectivity of the retro-reflector, thus realizing the desirable contrast ratio.

[0019]

Further, in the foregoing reflective liquid crystal display device, at least one lens sheet is provided on a front surface of the retro-reflector. With this arrangement, it is possible to improve the retro-reflectivity of the retro-reflector, thus realizing both desirable brightness of white state and a desirable contrast ratio.

[0020]

Further, in the foregoing reflective liquid crystal display device, the retro-reflector is preferably any one of a corner cube array, a micro sphere array, and a micro lens array. With this arrangement, it is possible to realize both desirable brightness of white state and a desirable contrast ratio.

[0021]

Further, in the foregoing reflective liquid crystal display device, the reflective liquid crystal display device adopting the corner cube array is so arranged that light absorbing sites are provided on vertices and sides of the corner cube, or light reflected at the vertices and the sides

of the corner cube is shielded. With this arrangement, it is possible to prevent a problem of irregular reflections from the vertices and sides of the corner cubes, which is inevitable in the production of the corner cubes. As a result, it is possible to realize both desirable brightness of white state and a desirable contrast ratio.

[0022]

It is preferable that the liquid crystal layer adopted to the foregoing reflective liquid crystal display device be the light scattering liquid crystal. Particularly, the following liquid crystals are preferable: a polymer-dispersed-liquid crystal; a liquid crystal gel; a cholesteric liquid crystal which is rendered scattering by controlling the domain size; and a polymer-dispersed-liquid crystal, having the holographic function, which switches between the transmissive state and the reflecting state, and is rendered scattering by exposure of scattered light.

[0023]

[EMBODIMENTS]

The following describes embodiments of the present invention with reference to attached drawings. Fig. 1 is a cross sectional view showing a configuration of a reflective liquid crystal display device in accordance with the

present invention. A liquid crystal layer 1 is sandwiched between an incident substrate 6 and an opposing reflection substrate 7. The reflection substrate 7 is provided with retro-reflectors 8. The retro-reflectors 8 used in the embodiments of the present invention are prepared by molding acrylic resin using a mold and by depositing silver on a reflective surface thereof to a thickness of 2000 Å.

[0024]

A pair of substrates 6 and 7 respectively have electrodes 4 and 5. Voltage applying means for the pair of the electrodes 4 and 5 may be activematrix elements, or the like. The present invention is not limited by the type of voltage applying means employed. The alignment films 2 and 3 are coated on the electrodes 4 and 5, respectively. These alignment films 2 and 3 serves as planar alignment films, which horizontally align the liquid crystal in the liquid crystal layer 1 while no voltage is applied. This embodiment employed the planar alignment films. However, type of alignment film is not limited.

[0025]

This embodiment of the present invention uses the polymer-dispersed liquid crystal as one example of light scattering liquid crystal for the liquid crystal layer 1.

However, the present invention is not limited to this, and a similar result is obtained by adopting any of the following liquid crystals.

[0026]

Namely, the light scattering liquid crystal may be a polymer-dispersed-type liquid crystal, a nematic-cholesteric phase transition liquid crystal, a liquid crystal gel, or the like. Further, the light scattering liquid crystal may be liquid crystal whose mode is switched between the transmissive state and a state in which at least scattering effect is rendered. For example, it is possible to employ cholesteric liquid crystal which is rendered scattering by controlling a domain size of liquid crystal molecules, and which switches between the transmissive state and the reflecting state, or polymer-dispersed-liquid crystal, having the holographic function, which is rendered scattering by the exposure of scattered light, and which switches between the transmissive state and the reflecting state.

[0027]

The polymer-dispersed-liquid crystal is obtained by placing a uniform mixture of a low-molecular-weight liquid crystal composition and pre-polymer between the substrates, and by polymerizing the pre-polymer therein.

As long as the polymer-dispersed-liquid crystal is obtained by polymerization, type of the polymer-dispersed-liquid crystal is not limited. A cured material (UV light curable liquid crystal) is used in the embodiment of the present invention. This cured material is obtained by exposing a mixture of a UV curable liquid crystal prepolymer and a liquid crystal composition to an activation light such as UV light. By using the UV light curable liquid crystal as the polymer-dispersed-liquid crystal, a heating process is not required when polymerizing the polymer liquid crystal. In this way, damages to other members can be prevented.

[0028]

For example, it is possible to adopt a prepolymer liquid crystal composition, showing a nematic crystal phase at room temperature, the polymer liquid crystal composition produced by adding a small amount of a polymerization initiator (product name: Irgacure 651, provided by Cibageigy) to a mixture of a UV curable liquid crystal prepolymer and a liquid crystal composition (product name TL213 of Merck & Co., Inc.; $\Delta n = 0.238$) at the weight ratio of 20:80.

[0029]

An incident ray on the liquid crystal layer so fabricated is modulated in accordance with the scattering

and transmissive states of the liquid crystal layer that has aligned in response to an applied voltage. It should be noted that, in the present embodiment, the liquid crystal layer has the scattering state under applied voltage, and the transmissive state under no applied voltage.

[0030]

The following explains display principles of the foregoing reflective liquid crystal display devices. First, an operation of white state will be described. Under applied voltage, when light is incident on the liquid crystal layer 1 in the scattering state, the steering light and forward scattered light through the liquid crystal layer 1 are reflected at the retro-reflector 8 and then scattered as they again pass through the liquid crystal layer 1 in the scattering state, thereby returning more light, not only the backward scattered light, to the viewer (observer). Here, in addition to the inefficient backward scattered light, the forward scattered light passing through the liquid crystal layer 1 are used, thus obtaining highly bright display.

[0031]

The following explains an operation of a black state. Under no applied voltage, the liquid crystal layer 1 is in the transmissive state. Tracing the light path onto an eye of the observer of the display, the light is refracted by the

incident substrate 6 and the liquid crystal layer 1, and eventually reaches an area in the vicinity of the observer's eye. Here, the outgoing ray which the observer sees is entirely the incident ray from the area in the vicinity of the observer's eye. Here, the black state is effected when the area in the vicinity of the observer's eye is sufficiently small to the extent where no light can make up a light source, e.g., smaller than the black part of the eye.

[0032]

[Fifth Embodiment]

In this embodiment, a plurality of reflective liquid crystal display devices having different pitches of smallest unit structures of the retro-reflector 8 were prepared, and a black state was observed by visual inspection. Specifically, twelve kinds of reflective liquid crystal display devices having retro-reflectors of corner cubes, micro spheres, and a micro lens array, each type of the retro-reflector having smallest unit structures of pitches 0.5 mm, 5 mm, 10 mm, and 25 mm, were prepared.

[0033]

The result showed that the retro-reflectors of the corner cube array, the micro spheres, and the micro lens array all realized a desirable black state with the pitches of 0.5 mm and 5 mm. The retro-reflectors of the respective

types with the pitches 10 mm and 25 mm resulted in a black state that was too bright, reflecting the eye lid and the eyebrow at the retro-reflectors.

[0034]

The following examines this result with reference to Fig. 2. When the observer is observing the center or near center of a smallest unit structure of the retro-reflector, the location of the light source of the observed light is in the very vicinity of the observer's eye. That is, in this case, the ray 10 which is incident on the reflective liquid crystal display device from the very vicinity of the observer's eye is reflected by the retro-reflector and the observer sees the outgoing ray 11.

[0035]

Further, when the observer is observing an upper end portion of the smallest unit structure of the retro-reflector, the location of the light source of the light which the observer sees is below the observer's eye. That is, in this case, a ray 12 which is incident on the reflective liquid crystal display device from the area below the observer's eye is reflected by the retro-reflector and the observer sees an observer outgoing ray 13. Here, when the pitch of the smallest unit structures of the retro-reflector is larger, the observer will see the eyelid or

the cheek, depending on the pitch size.

[0036]

Further, when the observer is observing a lower end portion of the smallest unit structure of the retro-reflector, the location of the light source of the light which the observer sees will be an area above the observer's eye. That is, in this case, a ray 14 which is incident on the reflective liquid crystal display device from an area above the observer's eye is reflected by the retro-reflector and the observer sees an observer outgoing ray. Here, when the pitch of the smallest unit structures of the retro-reflector is larger, the observer will see the eyelid or the eyebrow.

[0037]

Therefore, the image mirrored by the smallest unit structure of the retro-reflector has a length 17, which is two times a pitch 16 of the smallest unit structure of the retro-reflector. That is, in order to realize a desirable black state, the image within a plane of the length 17, which is two times the pitch 16 of the smallest unit structure of the retro-reflector, needs to be smaller than the black part of the eye, and, considering that the size (diameter) of the black part of the eye is about 10 mm (Encyclopedia of the eye, Yasumasa Okuzawa; published

by Higashiyama Shobo), it can be deduced that the pitch 16 of the smallest unit structure of the retro-reflector needs to be not more than 5 mm, which coincides with the result in the present embodiment. Thus, it was shown that the pitch 16 of the smallest unit structure of the retro-reflector needs to be not more than 5 mm.

[0038]

In view of the foregoing result, the inventors of the present invention have devised a novel measurement system as shown in Fig. 9. The light from a projector is projected on the center of the semi-sphere with the same luminance in all directions. The light from the projector is received by a detector 23 which is disposed in a direction normal to the measurement surface. Here, the diameter of a photo-detecting area of the detector 23 is set to 1 cm^2 in conformity with the size of the black part of the eye, and a viewing angle of the detector 23 is finely adjusted to exactly cover the smallest unit structures of the retro-reflector in the measurement. The reflectance of the lambertian diffused reflector is considered to be 100 %. The result is shown in Fig. 10. As is clear from Fig. 10, the pitch 16 of the smallest unit structures of the retro-reflector needs to be 5 mm or less for a desirable black state.

[0039]

[Second Embodiment]

In this embodiment, measurements of reflectance and a contrast ratio were performed on reflective liquid crystal display devices which were produced using the retro-reflector 8 including a corner cube array. A total of five kinds of such reflective liquid crystal display devices, including two kinds of comparative examples, were produced for the measurement.

[0040]

A first device is a reflective liquid crystal display device 9 (structure shown in Fig. 1) wherein, with respect to the corner cube array making up the retro-reflector 8, light absorbing surface portions 18 at some of the planes of smallest unit structures of the corner cube array as shown in Fig. 3. This device will be referred to as "sample A", and a specific production method thereof will be described later. A lens sheet is disposed on the front surface of the incident substrate 6 in the present embodiment but the effect of the present embodiment can also be obtained by confirmation even when the lens sheet is placed directly on the retro-reflector 8. This device will be referred to as "sample B".

[0041]

A third device is the reflective liquid crystal display device 9 wherein, with respect to the corner cube array making up the retro-reflector 8, the light absorbing surface portions 18 in the form of a flat plate are formed at some of the planes making up the unit structures of the corner cube array as shown in Fig. 3, the reflective liquid crystal display device 9 being produced using a corner cube array whose edges such as vertices or sides are shielded against light. This device will be referred to as "sample C", and a specific manufacturing method thereof will be described later.

[0042]

A fourth device is the reflective liquid crystal display device 9 wherein no special treatment has been applied to the corner cube array making up the retro-reflector 8, i.e., all planes among the planes making up the unit structures of the corner cube array, other than the reflecting planes 19 of Fig. 3 (a) through Fig. 3(d), are light transmissive planes. This device will be referred to as "sample R1" as comparative example 1. A fifth device is a reflective liquid crystal display device 22 fabricated in the same manner as in the foregoing conditions, except that the retro-reflector 8 was excluded, and that an absorbing layer 32, as a substitute for the retro-reflector

8, was provided on a back face of the device. The foregoing measurement is carried out for this device as well. This device will be referred to as "sample R2" as comparative example 2.

[0043]

Fig. 6 shows schematic view of a measurement system. A projector 36 projects light with the same luminance in all directions of the semi-sphere. The light is received by a detector 23 provided at an 8° angle with respect to a normal direction of the measurement plane. Here, a regularly reflected component of the light has been excluded by a light-shield 24. The reflectance of the lambertian diffused reflector is considered to be 100 %.

[0044]

Fig. 7 schematically shows an example of a lift-off method used in a manufacturing process of the retro-reflectors used in the reflective liquid crystal display devices of sample A and sample C. First, a black resin is press molded using a mold, so as to make concave shape 25 (Fig. 7①). Thereafter, a resist 26 is applied by the screen printing method. The resist 26 is made of, for example, the material OFPR-800 (provided by Tokyo Ohka Kogyo Co., Ltd.), and is deposited to a thickness of 4 μm (Fig. 7②).

[0045]

Then, a resist 26 is pre-baked at 100°C for 30 minutes, and a photomask 27 is placed on the resist 26 for exposure. The photomask 27 used for the exposure process of samples A and C are photomasks respectively, as shown in Fig. 8(a) and Fig.8(b) (see Fig. 7③). Thereafter, the resist 26 is developed and silver is deposited on a reflection surface in the normal direction of the substrates, so as to form a thin film with a thickness of 2000 Å. The developer may be, for example, the NMD-32.38 % (provided by Tokyo Ohka Kogyo Co., Ltd. (see Fig. 7④). Then, the resist 26 is removed (Fig. 7⑤), and levelling is finally carried out by using a transparent resin 29 (Fig. 7⑥).

[0046]

The present embodiment described the lift-off method, but it is confirmed by the inventor of the present invention that it is also possible to employ an ordinary method of patterning a metal such as silver or aluminum after depositing it over the entire surface.

[0047]

The results of measurement of reflectance and contrast ratio are as follows.

Sample A: reflectance 35% contrast ratio 18

Sample B: reflectance 40% contrast ratio 40

Sample C: reflectance 32% contrast ratio 21

Sample R1 (comparative example 1): reflectance 45% contrast ratio 3

Sample R2 (comparative example 2): reflectance 5% contrast ratio 17

It can be seen from the comparison of samples A, B, C and sample R1 (comparative example 1) that the contrast ratio can be greatly improved by providing the light absorbing surface portions at some of the planes of the smallest unit structure of the retro-reflector, by providing the lens sheet more toward the observer than the retro-reflector, or by providing the light shielding section for shielding light which is irregularly reflected at the edges such as the vertices or sides.

[0048]

Further, it was found from the comparison of samples A, B, C and sample R2 (comparative example 2) that improvement in reflectance was much greater in the reflective liquid crystal display devices using the retro-reflectors of samples A, B, and C.

[0049]

The reflective liquid crystal display devices of the present invention can also realize

input-device-integrated-type liquid crystal display devices by incorporating a touch panel, without resulting in poor display quality.

[0050]

[EFFECTS OF THE INVENTION]

As described, the present invention provides a reflective liquid crystal display device with a bright white state and a high contrast ratio. Further, with a provision of color filters, it is possible to obtain the reflective liquid crystal display device which is capable of clear multi-color display. Further, in the reflective liquid crystal display device of the present invention, wavelength dependency is low, and chromaticity is remarkably improved, when compared with a conventional method where a polarizer is used. Further, the reflective liquid crystal display devices of the present invention can also realize input-device-integrated-type liquid crystal display devices by incorporating a touch panel, without resulting in poor display quality.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A cross sectional view showing a structure of a reflective liquid crystal display device in accordance with First and Second Embodiments of the present invention.

[Fig. 2]

A diagram showing paths of a light beam incident on retro-reflectors used in the embodiments of the present invention.

[Fig. 3]

A diagram showing a unit structure of corner cubes used in the embodiments.

[Fig. 4]

A cross sectional view showing a structure of one modification example of a reflective liquid crystal display device of the Second Embodiment.

[Fig. 5]

A cross sectional view of a reflective liquid crystal display device used in the Second Embodiment.

[Fig. 6]

A diagram showing a structure of a reflectance measuring apparatus used for the reflective liquid crystal display devices of the second embodiment.

[Fig. 7]

Cross sectional views schematically showing a fabrication process of the corner cubes used in the Second Embodiment.

[Fig. 8]

A diagram showing a photomask used in fabrication

of the corner cubes of the Second Embodiment.

[Fig. 9]

A diagram showing a structure of a reflectance measuring apparatus used for the reflective liquid crystal display devices of the First embodiment.

[Fig. 10]

A graph showing a relation between a pitch of the smallest unit structure of the retro-reflector and reflectance in black state in accordance with the First Embodiment.

[REFERENCE NUMERALS]

1 Liquid crystal layer

1a Liquid crystal molecule

1b Polymer

2, 3 Liquid crystal alignment films

4, 5 Electrodes

6 Incident substrate

7 Reflection substrate

8 Retro-reflector

9, 21, Reflective liquid crystal display devices of the present invention

10, 12, 14 Incident ray

11, 13, 15 Outgoing ray

16 Pitch of the unit structure of the retro-reflector

17 Pitch of diffusion of the outgoing ray

18, 32 Light absorbing surface

19 Reflecting planes

20 Lens sheet

22 Reflective liquid crystal display device for comparison

23 Detector

24 Light shield

25 Black resin

26 Resist

27 Photomask

28 Metal thin film (silver thin film)

29 Transparent resin

30 Viewing angle of the detector

31 The smallest unit structure of the retro-reflector

[TITLE OF THE DOCUMENT] ABSTRACT

[ABSTRACT]

[OBJECT] To provide a reflective liquid crystal display device and a retro-reflector thereof having a bright white state and improved contrast.

[MEANS TO ACHIEVE THE OBJECT] A reflective liquid crystal display device has a pair of substrates, a middle layer provided between the pair of substrates, and a retro-reflector. A pitch of smallest unit structures of the retro-reflector is larger than 0 mm and not more than 5 mm.

[SELECTED DRAWINGS] Fig. 1